

D.3 Generalization of the Interference Equations of Annex C

D.3.1 Simplified Equations, Not Taking Into Account Antenna Discrimination

The interference equations of Annex C in an uplink-interference situation are:

$$C = P_D - A_{CA} - A_{FS} + G_{DES} + G_{SC} \dots \dots \dots (C.1),$$

$$I = P_I - A_{CA} - A_{FS} + G_{IES} + G_{SC} \dots \dots \dots (C.2),$$

and

$$C/I = (P_D - P_I) + (G_{DES} - G_{IES}) + F_{BW} \dots \dots \dots (C.3),$$

where C is the desired carrier level at the interfered-with satellite,

P_D is the transmitter power level of the desired carrier,

A_{CA} is the clear-air attenuation level in the transmission path,

A_{FS} is the free-space loss in the transmission path to the interfered-with satellite,

G_{DES} is the earth-station gain of the desired signal,

G_{SC} is the satellite-antenna gain of the interfered-with satellite,

I is the interfering carrier level at the interfered-with satellite,

P_I is the transmitter power level of the interfering carrier,

G_{IES} is the earth-station gain of the interfering signal, and

F_{BW} is a factor to account for the different bandwidths of the desired and interfering carriers.

The interference equations in an downlink-interference situation are similar but slightly more complex. They are:

$$C = P_D - A_{CA} - A_{D,FS} + G_{DSC} + G_{DES} \dots \dots \dots (C.4),$$

$$I = P_I - A_{CA} - A_{I,FS} + G_{ISC} + G_{DES} \dots \dots \dots (C.5),$$

and

$$C/I = (P_D - P_I) + (G_{DSC} - G_{ISC}) + F_{BW} - (A_{D,FS} - A_{I,FS}) \dots \dots \dots (C.6),$$

where most of the terms represent the same quantities as in the uplink equations, except that

A_{D,FS} is the free-space-loss of the desired downlink signal, and

A_{I,FS} is the free-space-loss of the interfering downlink signal.

These last two terms were identical in the uplink situation, but are very different in the downlink situation.

D.3.2 Generalized Equations, Taking Into Account Antenna Selectivity

These interference equations are generalized to take into account possible offset of any of the antennas involved. In the uplink direction the carrier and interference levels are:

$$C = P_D - A_{CA} - A_{FS} + G_{DES}(\theta_D) + G_{SC}(\phi_D) \dots\dots\dots (D.1),$$

$$I = P_I - A_{CA} - A_{FS} + G_{IES}(\theta_{I,U}) + G_{SC}(\phi_{I,U}) \dots\dots\dots (D.2),$$

and

$$C/I = (P_D - P_I) + \{G_{DES}(\theta_D) - G_{IES}(\theta_{I,U})\} + \\ \{G_{SC}(\phi_D) - G_{SC}(\phi_{I,U})\} + F_{BW} \dots\dots\dots (D.3),$$

where most of the terms are as defined above, with the following additional definitions for the angles involved:

- θ_D is the angle of the desired satellite off boresite of the antenna of the desired Earth station,
- $\theta_{I,U}$ is the angle of the desired satellite off boresite of the antenna of the interfering Earth station,
- ϕ_D is the angle of the desired Earth station off boresite of the antenna of the desired - signal satellite, and
- $\phi_{I,U}$ is the angle of the interfering Earth station off boresite of the antenna of the desired - signal satellite.

As in Annex C, it is noted that in Equation (D.3) the terms A_{CA} and A_{FS} are not present, since they are assumed to be similar if not common to the paths of the desired and the interfering carrier. The desired and interfering earth stations are assumed to be at similar locations, relative to the distances of either of the two satellites.

Another point which may be noted is that the interference is determined in clear-air propagation conditions; no account is taken of rain attenuation in these calculations. This is because a rain event and an interference event are each independently events with low probability; the joint probability of the two independent events, each with low probability, is extremely low and so is ignored in this analysis. A review of this aspect of the site-diversity interference-mitigation technique is discussed briefly in Section 5 of the report itself. The effect of having to also consider rain attenuation in the site-diversity strategy is a function of rain conditions at the site under consideration, and of the elevation angle of GSO satellites serving the area.

The generalized interference equations in the downlink direction are similar but slightly more complex. They are:

$$C = P_D - A_{CA} - A_{D,FS} + G_{DSC}(\phi_D) + G_{DES}(\theta_D) \dots\dots\dots (D.4),$$

$$I = P_I - A_{CA} - A_{I,FS} + G_{ISC}(\phi_{I,D}) + G_{DES}(\theta_{I,D}) \dots\dots\dots (D.5),$$

and

$$C/I = (P_D - P_I) + \{ G_{DSC}(\phi_D) - G_{ISC}(\phi_{I,D}) \} + F_{BW} - (A_{D,FS} - A_{I,FS}) \\ + \{ G_{DES}(\theta_D) - G_{DES}(\theta_{I,D}) \} \dots\dots\dots (D.6),$$

where $\theta_{I,D}$ is the angle of the interfering satellite off boresite of the antenna of the desired Earth station, and
 $\phi_{I,D}$ is the angle of the interfered-with Earth station off boresite of the antenna of the interfering satellite.

D.4 Antenna Characteristics

Equations D.3 and D.6 are general enough to consider interference mitigation techniques using the selectivity of any one of the four antennas affecting the interference process. These are the Earth station and the space station antennas of both the IRIDIUM and the SPACEWAY systems. The beamwidths of these antennas, taken from Reference 1, are as indicated in the following table:

Table D . 1

**Selectivity (Beam Width) of the Various Antennas
Involved in the Potential Interference Process
Between the IRIDIUM and the SPACEWAY Systems**

Antenna	Beam Size In the Uplink	Beam Size in the Downlink
IRIDIUM Satellite	5.0 °	7.4°
IRIDIUM Earth Station	0.24°	0.36°
SPACEWAY Satellite	1.0 °	1.1°
SPACEWAY Earth Station	1.1°	1.6 °

Of the four antennas, the most selective one is obviously the IRIDIUM Earth station antenna. That is probably so because the IRIDIUM feeder-link system uses relatively few Earth stations. (Five IRIDIUM Gateway Earth stations are planned in CONUS, for example, compared to the thousands

of user Earth stations in the SPACEWAY system.) In any case, the 0.24° beamwidth in the uplink and 0.36° beamwidth in the downlink of that antenna offers the greatest potential for isolation of the two networks through antenna discrimination. The remainder of this annex pursues that possibility to the extent possible, limited only by whether or not the selectivity of the IRIDIUM Earth station antenna contributes to the interference process. The sidelobe characteristics of those antennas are described in detail in Section A.2.3 of Annex A of this paper.

D.5 Isolation of the Two Networks Through IRIDIUM Earth Station Diversity

D.5.1 Isolation When IRIDIUM Also Uses APC as an Interference-Mitigation Technique

Annex C discusses the possible use of transmitter power in reserve in both the Earth-station and space-station transmitters of the IRIDIUM system to overcome or at least to minimize to the extent possible the interference from SPACEWAY transmissions during an interference event. In doing so, the IRIDIUM system could overcome uplink harmful interference into its satellite receiver, and almost overcome the harmful downlink interference into its Earth station receivers. However, in the process it would cause significantly harmful interference into both space station and Earth station receivers of the SPACEWAY system. The question answered here is

In the event that the IRIDIUM system used its APC system to the extent possible to overcome harmful interference into its own network, what angle separation away from the SPACEWAY satellite being in its Earth-station antenna boresite would be necessary to avoid harmful interference in both networks ?

D.5.1.1 Uplink Interference

Interference events into the IRIDIUM satellite receiver will only occur when the SPACEWAY Earth stations, the IRIDIUM satellite, and the SPACEWAY satellite are in an approximately straight line. It is assumed here that the minimum operational elevation angle for the SPACEWAY system is 30° , so that elevation angle is included in estimating the IRIDIUM noise and interference budget.

As indicated in Table B-1, the IRIDIUM Earth-station power level to provide a C/N of 10.7 dB at 30° elevation angle is -18.7 dBW. The maximum power level is +12 dBW, so there is a 30.7 dB margin for interference mitigation at a 30° elevation angle under clear-sky conditions. Using the simpler Equation C.3 to determine the uplink C/I in the IRIDIUM system without antenna discrimination of any kind, the worst-case C/I is -14.3 dB. (See Table C-1 of Annex C.) If it is assumed that the operator of the IRIDIUM system would use the available APC to bring the uplink C/(N+I) back to +10.7 dB, the Earth station power would be increased by 25 dB.

An increase in IRIDIUM Earth-station output power by 25 dB would lower the C/I at the SPACEWAY satellite from +14.0 dB (before IRIDIUM APC was applied) to -10.8 dB after 25 dB of APC is applied. In this situation the above general question becomes

What is the necessary off-boresite angle of the IRIDIUM Earth-station to raise the C/I in the SPACEWAY satellite from -10.8 dB to +6.9 dB, the minimum level of C/(N+I) to continue operation during the short interference event?

That question can be answered by setting θ_D , $\theta_{I,U}$, and ϕ_D all equal to zero in Equation (D.3) and solving for the necessary $\phi_{I,U}$ to provide a 17.7 dB reduction in interference. Based on Table D.2 above, that is almost exactly the 17.8 dB ($G_{\max} - G_1$) difference of the IRIDIUM Earth-station antenna. In this case the necessary separation angle ϕ_s is equal to the Earth-station-antenna's angle ϕ_m , ie. 0.313° . It may be noted that an actual Earth-station antenna gain drops significantly below the G_1 level at angles slightly greater than ϕ_m , and then rises again to the G_1 level at the peak of the first sidelobe, so a separation angle of ϕ_m or perhaps slightly larger is considered adequate.

Thus a combination of the temporary use of 25 dB of an available 30.7 dB APC budget in the IRIDIUM Earth station, and an IRIDIUM Earth-station-antenna separation angle of 0.313° from the direction of the SPACEWAY satellite, would reduce to acceptable levels the uplink interference between the two networks.

D.5.1.2 Downlink Interference

In this section the necessary separation angle ϕ_s is determined to avoid harmful downlink interference into both the IRIDIUM and SPACEWAY networks. As in the previous section, a 30° minimum elevation angle of both satellites during the interference events is assumed, based on the planned location of SPACEWAY Earth terminals.

Without the use of APC to increase the output power of the IRIDIUM spacecraft transmitter during an interference event, the worst-case C/I in the IRIDIUM system during that event would be -9.6 dB. (See Table C-3 of Annex C.) In such a scenario the worst-case C/(N+I) in a SPACEWAY earth station would be +8.8 dB, well above the minimum downlink C/(N+I) of 3.9 dB under worst-case conditions.

If the IRIDIUM system were to use the reserve APC satellite power to the maximum available, 15.1 dB at a worst-case 30° elevation angle, the IRIDIUM downlink $\{C / (N+I)\}$ would be +5.5 dB, and as a result the C/(N+I) of the SPACEWAY downlink would be reduced to -4.9 dB, 8.8 dB below the minimum required for continued operation. (See Tables C-3 and C-4 for details.)

If IRIDIUM earth-station's antenna discrimination is to be used to **simultaneously** correct both of those two excess-interference problems, ie

1. to enable the reduction of the IRIDIUM transmitter power level by at least 8.8 dB to protect the SPACEWAY downlink, possibly with a safety margin of 3 dB as is in the IRIDIUM link budget, and at the same time
2. correct a 5.2 dB deficiency in the IRIDIUM interference budget,

the minimum isolation of the IRIDIUM earth station antenna from transmissions from the SPACEWAY satellite must be at least $\{8.8 + 3.0 + 5.2\}$ or 17.0 dB.

The value $\{G_{\max} - G_1\}$ of the IRIDIUM earth station in the downlink is $\{53.2 - 36.1\}$ dB, (see Table A.1 of Annex A), or 17.1 dB. Thus the necessary θ_{ID} of Equation D.6 is 17.0 dB, again almost exactly equal to the ϕ_m of the earth station in the downlink, 0.44° . It is implied here that as well as providing an 0.44° mispointing of the IRIDIUM earth station antenna from the SPACEWAY satellite, the power level in the IRIDIUM satellite would be reduced $\{8.8 + 3.0\}$ or 11.8 dB to a - 15.0 dBW level. Even with that power reduction the performance of the IRIDIUM downlink is improved by $\{17.1 - 11.8\}$ dB or 5.3 dB. The net APC increase in IRIDIUM satellite power level would be $\{18.3 - 15.0\}$ or 3.3 dB.

Thus a combination of the temporary use of 3.3 dB of an available 15.1 dB APC budget in the IRIDIUM space station, and an IRIDIUM Earth-station-antenna separation angle of 0.440° from the direction of the SPACEWAY satellite, would reduce to acceptable levels the downlink interference between the two networks.

D.5.1.3 Summary of IRIDIUM Earth-Station Antenna Angular Separation Required When Full APC Is Used in the IRIDIUM System

Two antenna angular separations have been determined, each one to correct a specific short-term interference problem. These are:

- * 0.313° separation required to correct uplink interference in the SPACEWAY system; and
- * 0.440° separation required to correct downlink interference in both the SPACEWAY system and the IRIDIUM system.

The necessary angular separation to correct both problems would of course be the largest of the two, 0.44° .

D.5.2 Isolation When IRIDIUM Does Not Use APC as an Interference-Mitigation Technique

In the scenario examined here APC of the IRIDIUM system is **NOT** used as an interference-mitigation technique. It may be noted from Annex C that without the use of APC as an interference-mitigation technique, interference does not reach harmful levels in the SPACEWAY system, it only reaches such levels in the IRIDIUM system. If this interference is to be avoided, it has to be done so through the use antennas in the IRIDIUM system that do not point towards the interference. Specifically, harmful interference in the IRIDIUM system can be reduced to acceptable levels in the following two ways:

- * in the uplink, through use of spacecraft antenna isolation, and complementary use of an alternate Earth station antenna at the boresite of the space station antenna after it has been re-pointed to avoid the interference from SPACEWAY Earth stations; and
- * in the downlink, through the the use of alternate IRIDIUM Earth station antennas at nearby locations to avoid an interference from the tyransmitting SPACEWAY space station, in the same way that interference is avoided in conjunction with use of APC in the IRIDIUM system.

D.5.2.1 Uplink Interference

As indicated in Table C-1 of Annex C, the uplink C/I ratio may be as low as - 14.3 dB in the IRIDIUM system when APC is not used in that system. To raise the C/(N+I) to the minimum +7.7 dB during clear-air propagation conditions, when the clear-air C/N is 10.7 dB, the ratio C/I would also have to be increased from - 14.3 dB to +10.7 dB, an increase of 25 dB.

Without an increase in uplink power in the IRIDIUM system, the only isolation possible from the SPACEWAY system would be through **antenna isolation in the IRIDIUM spacecraft, not in the IRIDIUM Earth station**. It is noted that the IRIDIUM satellite antenna gain is only 30.1 dBi at boresite, so the angular separation from transmitting SPACEWAY Earth terminals at the edge of the service area of a SPACEWAY service area, perhaps fairly remote from the IRIDIUM Earth station itself, would have to be such that the gain of the IRIDIUM spacecraft antenna in the direction of those transmitting antennas would be only about 5 dBi.

The sidelobe characteristics of the IRIDIUM spacecraft antenna are as described by Annex III of Appendix 29 of the Radio Regulations, which are the same as described in Equations (D.7*) above, except that the sidelobe gain for antennas with (D/λ) less than 100 is

$$G(\phi) = 52 - 10 \text{ Log } (D/\lambda) - 25 \text{ Log } (\phi) , \text{ for } \phi_r \leq \phi \leq 48^\circ \dots\dots\dots (D.9a).$$

The IRIDIUM satellite antenna's boresite gain is 30.1dBi, which according to Equation (D.8) indicates a (D/λ) of 13.2 . Thus Equation (D.9a) becomes

$$G(\phi) = 40.8 - 25 \text{ Log } (\phi) , \text{ for } \phi_r \leq \phi \leq 48^\circ \dots\dots\dots (D.9b).$$

Based on this equation, the required separation angle to achieve an antenna gain of only 5 dBi would be 27°. Note that this is 27° from any concentration of SPACEWAY Earth stations, which may be considerably further than 27° angular separation from the IRIDIUM Earth station itself. To specify the separation distance on the ground it would be necessary to take into account the location of the SPACEWAY spacecraft antenna beams with respect to the possible future locations of IRIDIUM Earth stations, a complex and error-prone process.

D.5.2.2 Downlink Interference

In the downlink as well, there is harmful interference in the IRIDIUM system but not the SPACEWAY system. This will occur if the IRIDIUM Earth-station antenna that is tracking the IRIDIUM satellite finds the SPACEWAY satellite in its boresite, and if APC in the IRIDIUM system is not used as an interference-mitigation measure. Specifically, the worst-case downlink C / (N+I) ratio in the IRIDIUM system would be -9.6 dB, and in the SPACEWAY system the C / (N+I) would be + 8.8 dB.

To raise the downlink C/I in the IRIDIUM system to +10.7 dB, for the same reason as that discussed in Section D.5.2.1 above, an Earth-station-antenna discrimination of 20.3 dB would be required. Based on the information in Table D.2 above, the Earth-station-antenna discrimination angle would have to be such that the antenna was operating in the sidelobe 32 - 25 Log(ϕ) portion of its performance. An antenna discrimination D(ϕ) specified by the equation

$$D(\phi) \equiv G_{\max} - G(\phi) = G_{\max} - 32 + 25 \text{ Log}(\phi) \dots\dots\dots (D.10)$$

would be required, with G_{\max} equal to 53.2 dBi. To achieve a discrimination D(ϕ) of 20.3 dB, the required angular separation would be 0.92°.

D.5.2.3 Summary of IRIDIUM Earth-Station Antenna Angular Separation Required When No Use Is Made of APC in the IRIDIUM System to Combat Interference

In the uplink, the prime mechanism has to be IRIDIUM space station antenna discrimination when IRIDIUM Earth station APC is not used. To achieve the required discrimination, co-channel SPACEWAY Earth stations have to be 27° from the boresite of the IRIDIUM satellite's antenna.

In the downlink, IRIDIUM Earth station antenna discrimination is again the fundamental process for achieving the necessary isolation between the two networks. In this case an antenna separation angle of 0.92 ° is sufficient to achieve the required isolation.

D.6 Distances of Alternate IRIDIUM Earth Stations To Achieve the Required Earth Station or Space Station Angular Separation

An important parameter in the determination of the necessary distance between prime and alternate Earth station to achieve the necessary isolation between the two networks is the altitude of the IRIDIUM system: 780 km. At the very small angles involved in three of the four cases considered, ie. 0.313° , 0.440° , and 0.92° , the angles are small; these are only separation angles considered as being possibly feasible, and so are the only ones considered further. For these small angles the angle measured in radians, its Sine, and its Tan, are very similar, with percentage differences much smaller than other estimates made in this analysis.

In the simplest case, in which the IRIDIUM satellite is directly above the two Earth stations, the necessary distance between them such that they view that satellite with angles differing by a small angle ϕ is (780ϕ) km, when ϕ is expressed in radians. For the angles 0.313° , 0.44° , and 0.92° the required separations between the Earth stations are 4.3 km, 6.0 km, and 12.5 km respectively.

When the satellites have an elevation angle θ , this distance (780ϕ) km increases for two reasons. The first reason is that the distance to the IRIDIUM satellite increases from the minimum 780 km to the distance $\{780 / \sin(\theta)\}$. For the 30° minimum angle considered here, because the stated minimum elevation angle of the GSO satellite in the SPACEWAY system is 30° , the distance to the IRIDIUM satellite increases to 1560 km. Thus the minimum distances between the two Earth stations that are providing Earth-station diversity for one another increases to 8.5 km, 12.0 km, and 25.0 km respectively for the three required angle separations 0.313° , 0.440° , and 0.92° .

There is another increase in these required distance separations that may be necessary. Determination of the distances 8.5 km, 12.0 km, and 25.0 km assumed implicitly that the line joining an Earth station and the IRIDIUM satellite was perpendicular to the line joining the two Earth stations. That is of course possible under ideal conditions, and would result in the required distances 8.5 km, 12.0 km, and 25.0 km. However, if the relative angles between the two Earth stations and the IRIDIUM satellite were the **worst** possible rather than the **best** possible, the two Earth stations and the IRIDIUM satellite would be in a vertical plane. In that case, the required distances would increase by a further factor $\{1 / \sin(\theta)\}$ or 2 in the case where θ was 30° . The distances would then increase further to 17.0 km, 24.0 km, and 50.1 km.

These last distances are overly pessimistic for situations in which the interference events occur when the satellites are at an elevation angle of 30° , because the interference events occur at known locations of the satellites, determined by the location of the Earth stations and the GSO location of the SPACEWAY satellite. If interference with SPACEWAY satellites at 99°W and at 101°W were the only GSO-LEO interference events of concern in the design of the IRIDIUM system, the Earth stations could be situated ideally to combat that potential problem, and the distances 8.5 km, 12.0 km, and 25.0 km would apply. However, if the IRIDIUM Earth stations had to be located in such a way that interference with an unspecified number of GSO satellites had to be avoided, then perhaps the two IRIDIUM Earth stations should be located along an east-west line, and distances

less than the set { 17.0 km, 24.0 km, and 50.1 km } but greater than the set { 8.5 km, 12.0 km, and 25.0 km } would apply.

The actual current situation involving IRIDIUM Earth station complexes is that each complex will include three Earth stations, with one peripheral Earth station located 34 nautical miles or about 63 km in an "x" direction and 15 miles or about 28 km in a perpendicular "y" direction from the central Earth station, and a second peripheral Earth station located 63 km in the opposite "x" direction and 28 km in the same "y" direction. These distances are presumably chosen to combat rain attenuation when the IRIDIUM satellite is at low elevation angles. These distances between the Earth stations, 69 km between each of the peripheral stations and the central station, and 126 km between the two peripheral stations, are significantly greater than the required distances discussed above. **Thus it can be concluded that this Earth-station diversity technique can be employed without any further increases in Earth station separation beyond that chosen for mitigation of rain attenuation.**

D.6.3 Distances Required When the Satellites and the Primary IRIDIUM Earth Station are not Exactly in a Straight Line

The analysis in the above sections assumed implicitly that the path of the LEO satellite was the worst possible in terms of the LEO IRIDIUM Earth station causing or being subject to interference from the GSO SPACEWAY satellite. That worst-case arrangement is when the LEO satellite temporarily intersects the line between the LEO Earth station and the GSO satellite. If there are only two LEO Earth stations involved in the Earth-station-diversity activity to mitigate potentially harmful interference, there is a possible alignment of the primary Earth station and the two satellites that requires an even larger separation between the two Earth stations to avoid harmful interference: that is an alignment in which the LEO satellite travels a path slightly different from that "in-line" path, such that when the LEO Earth station tracks the LEO satellite the GSO satellite is in the edges of the main beam of the Earth-station's antenna, and some isolation is provided by the antenna of the primary Earth-station's antenna, but not enough to avoid harmful interference to one or both networks. If that path is such that puts the GSO satellite closer to the boresite of the second satellite than the "in-line" path, a larger separation between the Earth stations on the ground would be necessary to avoid harmful interference entirely.

To summarize, if there were only two LEO Earth stations involved, and if they were to be placed at points far enough apart to be able to correct for harmful interference caused by any possible path of the LEO satellites, the distance would have to be twice that determined in Sections D.6.1 and D.6.2 above.

This concern applies, however, only to the situation in which there are only **two** LEO Earth stations in the LEO Earth-station complex. If there are **three** such Earth stations, as there are in an IRIDIUM Earth-station complex, the situation is improved to the extent that the above doubling of Earth station distances is not necessary. The reasoning on which this conclusion is drawn is as follows:

If the path of the LEO satellite is "between" the central IRIDIUM Earth station and one of the two peripheral Earth stations, and those two Earth stations are placed with separations described in Sections D.6.1 and D.6.2 above, neither of those two Earth stations may be able to become the active LEO Earth station without harmful interference occurring to one or both of the two networks. However, in such a situation the third Earth station is even further away from the GSO satellite, measured in terms of the angle between the boresite of that Earth station's antenna and the direction of the GSO satellite, if it is tracking the LEO satellite. Thus its ability to avoid a harmful interference situation is even better than if the LEO satellite's path was "in line" with the central Earth station.

The conclusion drawn from this consideration of different flight paths of the IRIDIUM satellite in a possible interference-causing situation is that when there are three LEO Earth stations involved in roughly a straight line, as there are in the design of an IRIDIUM Earth-station complex, the worst possible flight-path of the LEO satellite from the perspective of having to place the LEO Earth-station antennas far enough apart to avoid harmful interference into one or the other network is the flight path in which the satellite is temporarily "in line" between the central Earth station and the GSO satellite. That is the situation analyzed in Sections D.6.1 and D.6.2 above, and so the conclusions reached in these sections in terms of the necessary spacing between Earth stations apply to **all** LEO satellite flight paths, not just the "in line" one.